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ABSTRACT

In this paper, under the assumption of a substantial manned space orbital program, we address the uses of man and manned space programs to support "operational" Earth applications. Potential space applications have been identified by NASA and recently by the National Academy of Sciences -- National Research Council Summer Study on Space Applications, in the fields of meteorology, oceanography, Earth resources, geography, geodesy, communications, navigation and traffic control.

The Summer Study, concerned with the next 5-10 years, is optimistic about the benefits obtainable from orbital flight. The participants postulate a substantial automated program to obtain these benefits; they remark that the use of manned vehicles "does not at present appear economically desirable and urge that the manned program "stand on its own feet."

However, this paper addresses a time, 10-15 years in the future, when the manned R&D base includes large new capabilities. There are continuously manned space stations in several orbits, including near-Earth high inclination and Earth synchronous. There are capabilities for frequent low cost transportation, shuttle vehicles with orbit change capability, launch and retrieval of automatic satellites, centripetal "gravity", and large cargo weight.

We can see considerable usefulness for man in a large, capable space station along with automated satellites accelerating development, qualification, and shakedown, and extending the life and improving the performance of operational systems.

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PREFACE

This document was initially prepared as a staff White paper for the STAC Winter Study on the Uses of Manned Space Flight 1975-1985. In the course of the study, portions of section III on the "uses of man" were consolidated with the White Paper on Earth Sciences and Applications, and will appear in the appendix of the STAC report. Responsibility for the statements made rests with the authors.

BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D.C. 20024

SUBJECT: Uses of Manned Space Flight Earth Applications - Case 105-1

DATE: March 27, 1969

FROM: W.W. Elam
G.T. Orrok

TECHNICAL MEMORANDUM

I. INTRODUCTION

In this paper, under the assumption of a substantial manned earth orbital program, we address the uses of man and manned space programs to support "operational" Earth applications. Potential space applications have been identified by NASA, and, recently, by the NAS/NRC Summer Study on Space Applications, in the fields of meteorology, oceanography, Earth resources, geography, geodesy, communication, navigation, and traffic control.

The Summer Study is optimistic about the benefits obtainable from orbital flight. The participants postulate a substantial automated program to obtain these benefits; they remark that the use of manned vehicles "does not at present appear economically desirable" and urge that the manned program "stand on its own feet."

This recommendation is entirely proper. It must, however, be recognized that the automated program is "cost effective" because it rests on a ten-year history of NASA and DOD research and development. Launch vehicle development, launch facilities, and tracking and data acquisition facilities are not charged to a new automated program. This paper addresses a time, ten years in the future, when the R&D base includes some new capability - low cost transportation to orbit - and the harnessing of the Manned Space Flight capability developed for the Apollo Program. This capability includes readily accessible space stations in several orbits.

Considering cost-effective applications for flight today, in 1968, the only rational role - or better, position - for man is on the ground, participating in design, development, control, and analysis of data from unmanned satellites. In the middle to late 70's, given the ground rules of this study, we can see considerable usefulness for him in space, accelerating the development and increasing the reliability of the applications.

Although we did not examine making Earth applications observations from a lunar base in any detail, it is our preliminary conclusion that little, if any, additional utility would be gained over making such observations from Earth orbiting space stations in geosynchronous orbits.

The body of the text includes, a fairly detailed summary of the Applications worked on by the Summer Study, a discussion of "potential benefits" and a discussion of which applications appear "consistent" with a manned program of this scope.

II. PAST STUDIES ON THE ROLE OF MAN IN EARTH APPLICATIONS: THE WINTER STUDY DIFFERS

This section reviews past studies on the usefulness of man in space. A general discussion is followed by conclusions of the NAS/NRC Summer Study on Space Applications and the assumptions of the Winter Study; these lead to the distinct conclusions of this white paper.

A. General

There have been a number of NASA and contractor studies partially directed at the use of manned vehicles to support Earth applications (See A-2, A-5, C-1, C-2, C-7, D-6, D-7 and D-8).

They cite some characteristic advantages applicable to operations. Included among these are:

1. Quality data assurance through the capability for calibration, modification, maintenance and repair in space;

2. Flexibility of control, adjustment and modification of instruments to match the instruments with the phenomena under observation;

3. The advantage of the presence of man as an observer;

4. Greater capability to carry correlative and comparative sensors;

5. Return of high quality, hard copy data.

Note that the first three deal with man, per se; the last two deal with necessary properties of manned systems, which could be realized with automated satellites as well.

Most of these will be discussed further in sections III and IV. The advantages of hard copy data are summarized in Appendix A.

Several references address the advantages and disadvantages of man himself for performing useful work in space (See A-3, A-11). It is clear that in any system where most of the sensing is routine and repetitive, man should not be an "on line" part of the system. Good machines make fewer sporadic errors, perform well-defined operations more precisely, and are not subject to "bad days," indigestion, or sleep.

The Thompson report (A-2) summarizes this point aptly: "Man's role in this program will add flexibility and reliability to the use of complicated instruments and sensors that are automated to the maximum degree that the designer's knowledge of requirements and his ingenuity will permit."

These references cover the generalized "usefulness" of man. A more pertinent question may be, for a given set of planned accomplishments, is a particular manned system desirable? For near term operational Earth applications and the Apollo Applications Program (AAP), the next section suggests the answer is no.

B. <u>Summer Study on Space Applications</u>[A-1]

This study, made by the National Academy of Sciences - National Research Council for NASA, is the most complete and authoritative study of potential applications of Earth oriented satellites. It will be summarized in Section V. Dealing generally with the next six years, the study identifies "realistic" space applications and postulates feasible automated systems for accomplishing them. The alternate, manned program is presumably the AAP.

With regard to the manned program they state:

> "We believe that the manned program has provided technological developments of importance to many aspects of space flight and the use of space. It is expected that this will continue. In particular, the large booster program, tailored to the requirements of particular earth orbits, will find applications in the orbiting of heavy payloads for a variety of purposes. Additionally, this program will provide significant opportunities to test sensors and to prove out techniques useful to

applications and considered by this Study. *However, the use of manned vehicles per se does not at present appear necessary or economically desirable for the operation of the various space-applications systems considered by this Study. We believe that the systems proposed for providing near-term practical and economical benefits to the United States public and to mankind generally will be achieved more effectively and economically with automated devices and vehicles.**

"We recommend, therefore, that these programs, manned and unmanned, be evaluated independently, i.e., each should stand mainly on its own feet."

As noted, the Summer Study findings are based on a program for the next six years, the time scale of the Apollo Applications Program (AAP). The disadvantage of this manned program were stated in this Summer's Space Applications Program Memorandum (C-2) and are summarized here.

1. "Man in space" is still in relatively early stages of development, and so dedicated manned flights for applications are premature.

2. Manned flight orbital inclinations are so constrained by safety considerations that the required high inclinations are not possible.

3. Operational systems will be automated; therefore, development flights should be automated.

4. Unmanned flights have a definite cost advantage.

For AAP, there can be little argument with the first two points. These and other conclusions of the Summer Study and of the Program Memorandum are open to reconsideration when, as in this study, a later time and a radically different manned program are considered.

C. The Winter Study Guidelines

STAC has been asked to consider the usefulness of manned space flight in various disciplines, given a substantial manned program. The time is the mid 70's to the mid 80's. In contrast with the limited AAP flights, there are continuously manned space stations in several orbits, including near-earth high inclination and earth synchronous. Transportation of personnel and materials to the station is

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*Italics ours.

frequent (every few weeks) and very low in cost--$10 to $50 a pound. Shuttle vehicles with a substantial orbit-change capability are available. Automated satellites may be launched into and retrieved from a variety of orbits. Centripetal "gravity" is available as needed, and cargo weight can be very large.

This Winter Study program is at least grossly practical. It represents a national Research and Development investment not out of line with NASA's previous budget history. STAC is asked to consider, then, how useful such a capability would be. For Earth Applications, the major shortcomings of AAP are removed. It appears, as developed in the next two sections, that there is substantial usefulness.

III. OPPORTUNITIES OFFERED BY THE WINTER STUDY PROGRAM: EXTENDED ROLES FOR MAN

A. General--The Space Systems

In 1968, the men on the ground are effective through the research and development investments of the preceding ten or more years. They work with manufacturing facilities, test facilities, the launch complexes, and the tracking networks. All of these focus on relatively small automated satellites.

For the Winter Study, these facilities are assumed augmented by an additional research and development investment, which includes the space stations and a highly competent transportation system. A variety of activities is carried on--e.g., the station are multi-disciplinary--and crew time is available to an arbitrary degree. One may postulate a few man-hours per week, or a reasonable number of full time specialists. The Earth Applications observations are made in part by automated satellites and in part by on-board instruments. The following sections deal with the man's interactions with on-board instruments and with automated satellites if accessible to the crew.

B. Exploratory Development

The scientific exploration of the Earth from space will stimulate potential users to conceive "operational applications." A particular user will pursue "proof of concept." For this, he requires sample data. These data may be available from archives. If archival data are inadequate, an "exploratory experiment" would be performed in the terrestrial case. Available equipment would be used. The Winter Study postulates a flexible Earth Sciences laboratory in orbit with an Earth scientist generally in residence. This facility, with the operator if required, is certainly available for "proof of concept" data, at some reasonable incremental cost.

C. <u>Development Phase</u>

The potential application could involve new software for an existing instrument (for instance, a metric camera or scanning spectrometer), the development of a new instrument or of an automated satellite. Development can proceed without immediate tests. However, in the early phases, many design choices are open which can be resolved empirically, using a working breadboard on the station. The cognizant engineer could perform not yet automated functions manually analyze and discuss the data with his cohorts on the ground, and make modifications <u>in situ</u>.

As the data approach "operational" quality,they may be useful in testing the ground portion of the system--e.g., the way in which crop data are distributed to farmers.

In the advanced phases of development there may be advantages in performing qualification tests and engineering shakedown in space. Thermal vacuum chambers and solar simulators are expensive and imperfect tests. Direct tests in space are less controlled (e.g., earth occultation) but without doubt realistic.

Shakedown involves operation of the final device; on earth it is customary to have a continuing capability for final tweaking, tuning, checkout, and last minute changes. If difficulties arise with which the astronaut cannot deal, the device can be returned to Earth for further work. Development costs for automated satellites have run $32,000/pound in the past; even with a considerable reduction in this figure, low cost ($10-$50 a pound) transportation permits a number of trips to orbit and back.

Use of man in the development phase will be "practical" if development time can be significantly shortened. We postulate that the capability to make real time adjustments with a relatively quick "feed back" of the results will involve much fewer man hours and a reduced development time scale as compared to an iterative development process involving sequential flights at relatively long intervals (∼ one year) with each flight requiring many supporting man hours.

The man involved in this development activity understands both his disciplines and his equipment. He has a flair for unusual occupations. Perhaps the oceanographer who sails for Woods Hole Oceanographic or Scripps is closely related. One would expect to find him a versatile, very interesting kind of character.

D. Operational Phase - Automated Systems

The applications described by the Summer Study (see Section V) are fairly cut and dried once they reach the operational phase. Procedures are well defined, and it would be foolish not to automate their nominal operations. There is a design freedom, using the man, to perform off-nominal operations (e.g., initial deployment), and to respond to contingencies (repair). This kind of man-instrument interaction is covered in Section IV. The man is involved with a given instrument only rarely, and he functions as a reasonably creative technician.

E. Operational Phase - Manned Systems

In addition to providing data assurance by providing support to sensing systems which are nominally automated, the manned station can, with some specialized equipment, lend itself to certain applications for which an automated sensing system would be less practical. These applications are associated with certain earth phenomena or events which are unusual, or of small extent in time and space. Either through versatile control of high performance instruments or as an observer man can accomplish concentrated, non-routine sensing of this type of phenomena. Specific examples include storms, incipient storms, frontal zones, and jet stream zones in meteorology; iceberg areas, storms, fish schools, and red tides in oceanography; fires, fire damage and storm induced changes in geography; and also floods, acute air and water pollution; and large scale cartographic and thematic mapping.

This intensified sensing would be done as a result of astronaut observation in some cases but more likely based on information from ground control.

In order to make this type of contingency observation, it is of course necessary for the observing platform to be in the right place at the right time. This is a relatively minor problem for stations in geosynchronous orbit; at these altitudes high resolution sensing is difficult but feasible. In the course of the Winter Study, there was serious discussion of a 120" telescope for Earth observation. In polar orbit a satellite passes over a given low latitude target at most twice a day.

F. Conclusions

Given the Winter Study program it appears that the development programs leading to operational applications could be speeded, using the space station facilities. There may, further, be some real benefits to be reaped from the occasional use of the multi-instrument manned laboratory for certain special tasks. Most "operations," however, are cut and dried; they will be automated whether accommodated on the manned spacecraft or not. The next section deals with these instruments. It appears to the authors that provided instrument requirements (orbit inclination, etc.) are met there may be real advantages in ease of design and incremental cost in building these automated instruments to work with men, on board the space stations of the Winter Study Program.

IV. IMPACT OF THE WINTER STUDY PROGRAM ON OPERATIONAL EARTH APPLICATIONS: INSTRUMENT DESIGN, EFFECTIVENESS, AND COST

Considering a particular task, are there ways to achieve it which are simpler, more effective, or cheaper on a manned space station, or on an automated space craft launched from and retrievable by the station? In attacking this question, we identify some difficult requirements which the station must meet; we also isolate ways in which the man can fruitfully interact with the apparatus; the first three sub-sections deal with cost and size.

A. Use of Incremental Costs

Based on past experience R&D costs will not be charged to the user. The incremental cost of serving a user will be charged to the user plus some share of the cost of the station. As a manned station will have multiple objectives the merit of which are difficult to compare quantitatively, an application users share of the cost of the basic station cannot be estimated, being a matter of broad policy. "Inexpensive, unmanned spacecraft" are inexpensive largely because they use facilities resulting from NASA and DOD Research and Development funds over the last ten years. The Winter Study Space Program provides precisely analogous facilities, paid for by Research and Development over the next ten years. Table IV-A makes the "unmanned spacecraft" point.

TABLE IV-A

COSTS OF AUTOMATED SPACECRAFT

DEVELOPMENT	OPERATIONS
INSTRUMENT DEVELOPMENT	UNIT COSTS
DATA ANALYSIS DEVELOPMENT	UNIT COSTS
SPACECRAFT INTEGRATION	UNIT COSTS
SPACECRAFT DEVELOPMENT	UNIT COSTS
(NO LAUNCH VEHICLE R&D)	LAUNCH VEHICLE UNIT COSTS
(NO LAUNCH COMPLEX R&D)	LAUNCH OPERATIONS UNIT COSTS
(NO TRACKING AND DATA R&D)	TRACKING AND DATA ACQUISITION (?)

We would expect the "venture capital" required for an instrument on a manned station to fall under the same line items enumerated above. "Spacecraft development" might be referred to a pro-rated share of the Earth looking module.

B. Low Cost Transportation

The launch costs chargeable to a given package of instruments will be lower than those using conventional launch vehicles. The guidelines describe a reliable, reusable manned transportation system; the cost of lifting discretionary payload to low Earth orbit is $10-50 a pound. Since conventional vehicle costs to low earth orbit are already quite modest ($2000-$4000/pound) relative to payload costs ($32,000/pound), this point will be of importance mainly in relation with the following paragraphs.

It is significant that the total launch costs of such a reusable launch vehicle (2-5 million dollars) may be comparable with those of conventional smaller launch vehicles. Thus, the manned launch or retrieval of a small payload such as an individual satellite is not unreasonable.

C. Effectiveness: Module Size

An Earth-looking module , on a manned spacecraft or occasionally tended by man, will be larger and more complex than the average unmanned spacecraft.

The large system can accumulate many instruments employing each basic sensing technique. For example, in infrared imagery the limited capacities of a smaller system may dictate that one instrument be flown and the most useful spatial resolution be 200 feet. The larger system can provide capability to take such imagery at other spatial resolutions which will better satisfy the requirements of particular users. The required versatile instrument control is provided on a manned station. With such a basic stable of instruments the average "application" may be accomplished by "lease" of existing apparatus, rather than by the development of new devices.

It is of course essential that the large space platforms be designed to avoid excessive experiment integration costs. If the "user" has a clean, standard interface to design to, his integration costs should be similar to or lower than those he incurs in using a smaller automated satellite.

A disadvantage of the large, multi-purpose vehicle is "one-shot loss." That is, many instruments are lost when a spacecraft system fails. The provision of manned repair capability seems likely to tip the balance further towards larger systems.

D. Reliability and Maintenance

The principal alternates to repair are redundant systems and outright replacement of the vehicle by a "Chinese copy." Not all failures can be anticipated and prevented by redundancy, as indicated by the loss of OAO-1.

For individual applications, repair is economically more important as expected instrument lifetimes become large, because the "spare" becomes a larger percentage of the total cost. A spare vehicle hardly shows in a five year, five satellite program but is important in a five year, one satellite program. Repair also becomes important as the replacement cost of the repairable item becomes large.

The instruments and systems must be designed for repair. For critical space station systems, spare parts and diagnostic information must be on-board. For less critical items, and for automated satellites the low cost transportation system allows repair parts or even a trained repair crew to be sent up, if desirable.

E. Instrument Design

Design for manned flight may permit a somewhat simpler implementation. The crew can unpackage and deploy an instrument (or an automated satellite prior to launch). This simplifies mechanical design. Last minute checks of calibration and alignment relax the requirement that adjustments survive launch. Simplifications of this nature may reduce the cost of an instrument.

For a given application, the "natural implementation" may differ, if flown on a manned spacecraft. It may for instance involve the return of film rather than telemetry, where this choice is otherwise free in instrument design.*

F. Conclusions

If the principal charges for an operational application are incremental, it seems reasonable that appropriate operations can be performed less expensively on the station than on separately launched un-manned spacecraft. Low cost transportation will help, directly, as will a manned repair capability. The number of instruments already present may permit "leasing" rather than building new apparatus, and astronaut assistance will simplify certain design problems and thus reduce development cost. The principal negative factor, integration cost, may be met by standardizing instrument spacecraft interfaces.

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*We expect both film and telemetry will be important in the '75-'85 decade. Appendix A summarizes the advantages and disadvantages of each.

The next section summarizes the recent Summer Study on Space Applications and shows that a reasonable portion of proposed applications could in principle be accommodated on a manned space station; it is believed that many of the rest could be fruitfully serviced by it.

V. SUMMARY OF POTENTIAL EARTH APPLICATIONS: CONSISTENCY WITH THE WINTER STUDY PROGRAM

A. General: Summer Study

The briefing and seminars held in Woods Hole from July 31 to August 3, 1968 summed up two years of work by a Central Review Committee and twelve technical panels of the National Academy of Sciences. The purpose of the study was to advise NASA in the area of space applications. A panel of experienced businessmen was added in 1968 to assess the expected benefits.

The 1967 Summer Study Interim Report conclusions stated that "useful applications of space are unquestionably real, substantial, and potentially close at hand...the space program has broken the plausibility barrier." (Vol. I, p.3)

Table I in this section enumerates by discipline the potential applications considered by the Summer Study. It gives a good idea of the size and potential. Sub-section B summarizes this table; sub-section C contains summary remarks on total benefits estimated. Sub-section D summarizes the distribution of applications by orbit, and thus the requirements which the "Winter Study" program must satisfy.

For this paper, it is out-of-place to criticize the potential of the individual applications; the Summer Study has done so, and in most cases the practicality now rests on the results of experiments.

B. Potential Applications

This section reviews certain well-defined possibilities for obtaining "benefits" from earth orbiting satellites. Attention is focused on Table I, which is an attempt at highlighting the Woods Hole Summer Study, 1968. The horizontal portions of the table are addressed to discipline areas that were studied by panels of scientists, such as meteorology, geology, or communications. The vertical divisions divide the disciplinary areas in user needs, system requirements fo fill the needs, systems costs for an unmanned program over a seven-year period, precursors and readiness time for space systems, benefits, and comments. The column identified as systems costs is based on the work of the panel on Economic Analysis of the 1968 Summer Study. It estimates a total cost of the Earth Applications Program as here portrayed of about $1.4 billion, over a seven-year period, or $200 million per year.*

In the following, we will discuss some examples of applications set forth in Table I.

In meteorology, short and long range weather forecasts using satellite data are generally accepted as desirable and obtainable benefits, some of which have indeed materialized already. Numerous weather-dependent users are existent now. Meteorology is the only user area identified that has funded launch vehicles and spacecraft, tracking and ground networks, totalling about $100 million projected over a seven-year interval. COMSAT (not shown in Table I) is of course operational, and other, though not identified, funded programs exist in communications, and studies are underway in navigation and traffic control using ATS systems.

Meteorology is one user area that has firm requirements for continuous, global coverage from an integrated system of polar and geosynchronous satellites. Four geosynchronous satellites are required at any one time because of the limited global coverage available by any one system. In contrast, only one polar orbiter is required at any one time.

In oceanography, concrete areas are sea ice survey from space, sea state survey and traffic routing, coastal survey, and fish scouting. Aircraft are being used for these tasks to date, some at formidable expense. The USCG sea ice survey, for example, costs $2,000/hour for one C-130 aircraft, which adds up to millions of dollars per year. Fish spotter planes are used by all fishing concerns, depending largely on the human eye as a sensor.

Oceanography also requires polar and geosynchronous systems. Two geosynchronous systems and one polar system are in orbit at any time. The geosynchronous satellites are over the Atlantic and Pacific Oceans. Sensors, packages, resolution requirements, and orbital altitudes for the polar satellites are different from the meteorological satellites, even though the Summer Study specifies only vaguely "several 100 miles" as desirable.

*The Summer Study recommendations concerning the NASA Applications budget states that, "The level (100 million dollar/year) should be increased between 2 and 3 times."

In hydrology, fresh water inventory and snow survey have been carried out by ground work and aircraft. Some salt water intrusion and pollution studies from aircraft have been carried out, but no programs of national character are known as in meteorology or oceanography. Possibilities exist in monitoring the national resource, water; in understanding its dynamics, measuring flow, and identifying mixing and pollution processes and rates.

Again, geosynchronous and polar satellites are projected. One geosynchronous satellite (continential United States) and one polar satellite will be in orbit at all times.

In agriculture, concrete possibilities are crop census taking, yield forecast, and area crop status monitoring (drought, disease). All of these items have been done or are being done routinely by less reliable means than possible from space. They require high resolution (low altitude satellite or aircraft) observations.

Agriculture, forestry and geodesy require one polar orbiter at all times.

Cartography offers a concrete goal of having available for once, updated and complete maps of any area in the world. This is a prerequisite for the useful application of sensors to other earth resources disciplines.

Even though no satellite requirements are set forth, cartography will probably require at least one polar system for a four-year period, with one backup.

Geodetic space applications will bring one accurate network covering the world instead of several incomplete ones that are in use now. The inadequacy of the present networks is apparent at the conclusion of every major space launch when NASA, military, and tracking data disagree to the extent of several miles as to the impact point of a spacecraft.

Geodetic satellites projected include one low inclination and three polar orbiters (geodetic program), and one more low inclination and polar orbiter for gravity field studies.

Geological applications lie in the areas of disaster monitoring and locating ore bodies by space mapping. Disaster monitoring requires relatively simple systems with a small number of variables, such as temperature for volcanism. Increasing the probability of locating ore bodies by space mapping is possible due to the synoptic view afforded us in large coverage photos and due to the fact that ore bodies tend to be connected with large structures which are often called guides to ore.

Geological satellite applications for the seven-year period projected are slim; three launches of polar orbiters with one-year lifetime appear adequate. In addition, a vigorous aircraft program over the western hemisphere using sidelooking radar sensors is projected that will tie in with space photography or imagery.

Concrete communications applications are point-to-point, points-to-point, and broadcasting satellites, with the networks being applied to more and more selected groups.

The study projects four simultaneously launched data collection relay satellites (DCRS), with a 4-5 year lifetime. Other configurations call for three geosynchronous spacecraft and two sun-synchronous polar orbiters, to provide full coverage of the earth.

It is of interest to sum up the interesting array of geosynchronous and polar hardware that the NAS Summer Study projected would be procured, launched or in the stand-by mode during a four-year operational period of an unmanned space applications program at a spending level of about $200 million/year. All in all, 59 launch systems would be procured.

This is not a "proposed program," but rather a hypothetical case representative of the orbital coverage required and the scope of the required space hardware. A practical program (as currently planned by NASA) would both exploit commonality and achieve better satellite lifetimes. Nevertheless, the Summer Study felt its program was appropriate in cost. Even with commonality, its price tag would approach a billion dollars. In the later 70's an investment for Earth applications of this magnitude is not badly out of scale with the development costs of a large, manned space station program.

C. Dollar Benefit

A number of attempts have been made to estimate world-wide or domestic "dollar benefits" from a vigorous space applications program. Table II lists estimates made by TRW, the 1967 NAS Summer Study, the 1968 NAS Summer Study, and the results of five case studies made by Planning Research Corp. The reader is warned against making a cursory comparison of the results of the different studies because it is necessary to know the details of each study before a useful comparison can be made. For example under "geology (mined resources)" the 1967 NAS Summer Study figure is an estimate of the benefit derived from the use of good up-to-date geological maps such as could be produced from space systems. The 1968 NAS Summer Study figure on the other hand is a savings in the cost of producing the maps, compared to conventional means, and does not include the greater benefit obtained from the use of the maps. Also, the dollar figures given by the Planning Research Corp. are benefits derived over 20 years discounted to 1970. The PRC annual benefits would be less than "average" in the early years and greater in later years.

In summary, the estimates do vary widely, but appear to be on the order of a billion dollars a year.

A reasonably typical set of qualifying remarks - and a startling estimate of benefit! - is given by Thompson (B-9), discussing the World Weather Watch:

> "As was anticipated at the beginning of the investigation, many of the benefits - although evidently very large - are for the present only qualitatively apparent. Of those that are capable of quantitative assessment, some are expressed in non-monetary terms (saving in human life and health, for example), while others are complicated by the probable existence of secondary side-effects which may partially or wholly offset the primary gains.
>
> "Nevertheless, it seems clear that the overwhelming evidence points to the attainment of significant benefits, greatly exceeding the cost of implementing the World Weather Watch. A recent study of a proposed weather satellite system (reference D-4) reached the conclusion that the annual potential benefits of that system to the world would exceed $16 billion, about 50 times its estimated yearly cost."

D. Consistency With the Winter Study Program

The Space Applications Summer Study deals with the next six years. We assume, arbitrarily, that the satellite coverage will be comparable in the mid to late 70's, that is, that the successor programs in the '75-'85 time will have similar orbital requirements.

Orbits

Choice of orbits is set by factors such as ground coverage, spatial resolution, observation frequency, and illumination. Geodesy is a special example, with orbits set by the shape and gravitational potential of the Earth.

All other applications require ground coverage of most of the Earth. This leads to two orbital classes, high altitude (usually synchronous) and low altitude, high inclination.

Desire for high resolution observations leads to lower orbits.

Observation frequency moderates this. Continuous coverage of a given area implies synchronous orbit, or increasing numbers of satellites at lower orbits. Twice daily coverage of a given point (within 45° of the satellite ground track) can be obtained by one satellite from altitudes above about 600 nautical miles.

Requirements for constant illumination lead to sun synchronous orbits. Solar incidence angle depends on latitude and season. These orbits do cover most of the earth at constant time, however. Typical "requirements" are for 0900, noon, and 1500 local time.

There are always conflicts between requirements within the disciplines, the observables having substantial ranges of sizes and observation frequencies. The resulting system is a compromise.

Commonality Approach

The Summer Study '68 (A-1, p. 12-9) postulated a satellite system using common hardware. Table III shows the orbital positions occupied.

TABLE III

	POLAR		GEOSYN-CHRONOUS	LOW IN-CLINATION
	NO. -(ALT.)	LOCAL TIME	NO.	NO.
METEOROLOGY	ONE(600NM)	1200 HRS.	FOUR	
OTHER DISCIPLINES	THREE(LOW)	0900,1200, 1500 HRS.	FOUR	
GEODESY	ONE			ONE

Meteorology is given a separate system because of "unique" requirements which are not spelled out. One "unique" requirement may be complete daily coverage of cloud imagery, requiring the polar satellite to have a higher altitude than desirable for other disciplines. The separate geosynchronous families probably do not have unique requirements. The three polar satellites for non-meteorological disciplines are sunsynchronous and phased at three hour intervals (0900, 1200, and 1500 local time).

The occupation of orbital positions could be expected to grow, giving more continuous coverage from low orbits. The actual number of desirable geosynchronous positions probably does not exceed four; the number of satellites is already larger.

E. Model for the Winter Study Program

The Winter Study guidelines postulate stations in at least three orbits (low altitude, at low and high inclination, and synchronous).

The postulated Earth Applications program of Table III is a reasonable one which will provide the minimum coverage. Manned stations could not profitably replace all of the required satellites. The 600 nautical mile altitude is in the radiation belts and the geodetic satellite for gravimetric geodesy must be un-perturbed. A manned station in high inclination orbit, and a manned station in geosynchronous orbit could form a part of the required system, and the advantages of the manned system could be realized.

Pending further analysis, it seems advantageous to have the low altitude manned station NOT sun-synchronous. It would then drift through the illumination and ground coverage requirements of most applications. This would permit development testing of various systems. Operational applications requiring a modest frequency of observations (less than weekly) could be accommodated. This should include most agricultural, cartographic, and geological applications.

Applications requiring low altitude synoptic coverage require, a priori, many satellites and are less suited to manned spacecraft.

VI. SOME CRITERIA FOR AN EFFECTIVE MANNED PROGRAM

This section summarizes some criteria, stated as questions, which must be met if manned space flight, on the scale of the Winter Study, is to be "useful" in Earth Applications. The validity of the guidelines is critical, here, but is not addressed.

1. Will space-maintenance, data assurance, technology be far enough advanced, by the mid 70's to permit efficient design of "operational" application instruments for use on manned spacecraft?

2. Can sufficiently clean organizational and mechanical interfaces be presented to the "user" so that he will find the space station an attractive, easy carrier to work with?

3. Alternately, can the costs (effort) or instrument integration and qualification be reduced from AAP levels? It is advantageous to let in-flight "shakedown" replace some ground testing?

4. Can the space station respond quickly to the user's schedule?

5. From an overall NASA view (and the user's!) will it be less costly to use the space station than a carrier?

6. Will orbit change capability be such that the space station is the focus for the repair of satellites? Or will low cost transportation from the ground be more important?

VII. CONCLUSIONS

Under the assumption of a substantial manned Earth-orbital program we have examined the uses of man and manned space programs to support "operational" Earth Applications. The National Academy summer study was highly enthusiastic about the benefits obtainable from orbital flight; for the near term, they found the manned program unnecessary. In the late seventies, with low cost transportation to orbit, it appears that portions of the instrument development program may fruitfully be carried on in orbit. Large capable stations appear a useful ingredient, with automated satellites, in an operational program, particularly insofar as manned assistance and repair can be utilized to extend system life. There is indication, pending further analysis, that most applications requiring relatively infrequent observations could be accommodated on a single, high inclination station.

ACKNOWLEDGEMENTS

Dr. John Whinnery of STAC consulted with us closely during the generation of the paper and recommended certain special studies including the appendix. The emphasis on the usefulness of man in the development phase of Earth Applications (or other) instruments is his. B.E. Sabels made substantial contributions to the paper, including the preparation of Table I and much of the text of section V. We are grateful for extensive comments from many sources, though responsibilities for the statements made rests with the authors.

It was a pleasure to work to Dr. Mueller's enthusiastic guidelines; much of the positive flavor of the text represents our own intuition that such a space station would indeed be "useful" independent of the particular pacing of the discipline to which the paper is addressed, "operational" Earth Applications.

W. W. Elam
W.W. Elam

G T Orrok
G.T. Orrok

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Attachment
Appendix I
Bibliography for Uses of Manned Space Flight in Earth Applications

APPENDIX I

Comparison of Returned Photographic Film and Telemetered Images

Photographs or images are proven tools for many earth applications. Photography has had a secure place in planning for earth applications space systems. Recently, advances and anticipated advances in mechanical and electronic techniques have indicated that telemetered imagery may be more desirable for the majority of users and competes with film for the other users.

However, the routine return of film provides high quality, hard copy data, and provides data assurance for user disciplines such as geology, geography, and cartography. In these disciplines the "time constant" from data to product is on the order of months rather than hours or days.

The 1967 Summer study in the cartographic section (p.44) states, "With present or near-future technology, the use of television cameras with electrical transmission does not provide the metric quality required for mapmaking." No position on the requirement for cartography was taken in the 1968 Summer Study as there was no cartography panel. The report of the Geology panel states (A-1, 1.2-2),

> "---higher-resolution, capsule-dropped, hard film (in contradiction to telemetry), from one or two satellites only, may be justified in the singular case of geology."

The position of the Summer Study in support of hard copy film return has softened. As the complete reports of the 1968 Summer Study are not available as yet, it would be conjectural to state the reasons. However, the advances in telemetered imagery must be a significant factor. A question is implied, will hard copy film return be necessary in an operational system? This question and a comparison of photographs and telemetered imagery is now addressed.

Some advantages and disadvantages of hard copy film return and telemetered imagery are listed.

Hard Film Return

Advantages:

1) Economical storage volume

2) Three dimensional storage is implicit in the emulsion. Two dimensional "control" is critical for cartography. Uses of the emulsion depth include color photography, ultra-wide dynamic range films, and, in the laboratory, holography.

3) wide dynamic range

4) Comparatively better spatial linearity (metric quality)

5) No burden on telemetry system (Particularly important for peak rates)

Disadvantages:

1) Radiation sensitive

2) Dimensional changes in storage and development

3) Slow return to user

4) Takes up return weight and volume in returning spacecraft

5) Unnecessary extra steps if digital processing is used.

Telemetered Images

Advantages:

1) Quick return of data to users.

2) Direct input if digital processing is to be used

3) Acceptable linearity (metric quality) for many users.

Disadvantages:

1) Intermediate step of scanning, transmission, reassembly will introduce noise

2) Extremely high bit count for telemetry

3) State of art advances required in recording and storage devices

4) Difficult and costly advances in state of art require to achieve linearity (metric quality) for high resolution images covering fields of significant size (10^4x10^4 picture elements) useful for some cartographic and geology users. (Size of control components increases geometrically as size of image tube is increased) Unsolved linearity problems exist in optical mechanical scanners.

Summary and Conclusions

Telemetry system can provide the bulk of the imagery required including some useful cartography. Some cartographic and geologic applications will probably require hard copy film return. A decision as to whether hard copy film will be required can be delayed for 3-4 years pending experience in using imagery from space. However, in the broader view of a multi-purpose space station, research requirements in earth science will undoubtedly include a requirement for hard copy film return, which could be used for operational purposes.

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TABLE I

NAS-NRC 1968 SUMMER STUDY HIGHLIGHTS

DISCIPLINE	NEED	SYSTEM REQUIREMENTS	UNMANNED SYSTEM COSTS (IN $ MILLION) (PANEL FOR ECONOMIC ANALYSIS, P. 12-1 TO 12-35, 1968 DRAFT REPORT) R & D	INITIAL INVESTMENT	OPERATION AND MAINTENANCE	TOTAL	PRECURSORS AND READINESS TIME	BENEFIT	COMMENT
<u>METEOROLOGY</u> (METEOROLOGY PANEL, p. 9-10, 1967 27-29, 1967 4-1 TO 4-4, 1968	<u>ATMOSPHERIC SCIENCE</u> COMPOSITION PHYSICAL PARAMETERS GENERAL CIRCULATION ENERGY AND HEAT TRANSFER <u>SHORT-RANGE WEATHER FORECAST</u> LOCATION OF STORMS, FRONTS, ETC. MAPPING OF PRECIPITATION ATMOSPHERIC MOISTURE DISTRIBUTION <u>LONG-RANGE WEATHER FORECAST</u> CLOUD PATTERNS TEMPERATURE WATER VAPOR SURFACE BOUNDARY CONDITIONS MASS FIELD (DENSITY) MOTION FIELD	3 YEARS R & D, 4 YEARS OPERATION AIRBORNE AND SATELLITE (NIMBUS AND FOLLOW ON) SENSING OF WORLDWIDE EXTENT WITHIN THE SCOPE OF ESSA AND WMO (RESEARCH AND OPERATIONAL PAYLOADS) INTEGRATED SYSTEMS OF POLAR AND GEO-SYNCHRONOUS ORBITS TWO SYSTEMS OF TWO GEOSYNC. SATELLITES IN ORBIT AT ALL TIMES. TOTAL OF 5 MIN., INC. 1 SPARE. ONE POLAR ORBITER OER YEAR. TOTAL OF 5 LAUNCHES, INC. 1 SPARE GEOSYNC: COLOR CAMERA, POLARIZER, IR IMAGES, SOUNDER, BALLOON PLATFORM DATA CALL. POLAR ORB: IR STRIP MAPPER, IR SOUNDER	SPACE SEGMENT SPACECRAFT, SENSORS 8M GROUND DISPLAY 1M VEHICLE INTEGRATION 18M	VEHICLES (GEOSYNE) 45M SPACECRAFT (11) 90M GROUND STATIONS 8M VEHICLES* (POLAR) 15M SPACECRAFT* (11) 24M * IS FUNDED	LAUNCH PAD 30M GROUND NET 28M SYSTEM MANAGEMENT 5M LAUNCH PAD* (POLAR) 10M TRACKING * 30M * IS FUNDED	312M	TIROS - CLOUD COVER PICTURES ATS - SYNCHRONOUS ORBIT SPIN CAMERA WITH HEMISPHERIC COVERAGE AT 20 MINUTE INTERVALS NIMBUS- IR IMAGERY OF THE GLOBE TIROS - NIMBUS - ATS AND FOLLOW-ON	NO $ BENEFITS BY 1968 METEOROLOGY PANEL MODELS OF THE ATMOSPHERE FOR FORECASTING PURPOSES SHORT-RANGE AND LONG-RANGE FORECASTING WITH IMPROVING RESOLUTION, BENEFITTING A WIDE VARIETY OF BUSINESS, INDUSTRY AND PUBLIC USERS	SHORT-RANGE FORECASTING BASED ON SATELLITE METEOROLOGY IS OPERATIONAL AND IS AFFECTING NUMEROUS USERS ALREADY
			PROCESSING AND DISTRIBUTION SEGMENT BALLOONS 5M	DATA PROC EQUIPMENT 2M	DATA PROC. 8M BALLOONS 80M SYSTEM MANAGEMENT 15M GROUND NET 14M* * IS FUNDED		(SAME AS ABOVE)		LAUNCH OF A GROW SATELLITE (GLOBAL RADAR FOR OCEAN WAVES) WOULD INCREASE COSTS OVER FOUR YEARS BY $50M
			TOTAL BOTH SEGMENTS			124M 436M			
<u>EARTH RESOURCES</u> <u>OCEANOGRAPHY</u> (OCEANOGRAPHY PANEL, p. 12-13, 1967 34-37, 1967 5-1 TO 5-5, 1968	<u>COASTAL GEOGRAPHY</u> SHORELINE TOPOGRAPHY SEDIMENT TRANSPORT WATER EFFLUENTS SEA LEVELS AND SLOPES	3 YEARS R & D, 4 YEARS OPERATION 20-100 m RESOLUTION PHOTOGRAPHY ORBITS POLAR, SEVERAL 100 NM ALTITUDE (6 REQUIRED) IN ADDITION TO GEOSTATIONARY SATELLITES (3 REQUIRED, 2 SPARES INCLUDED)	SPACE SEGMENT SPACECRAFT AND SENSORS 8M	VEHICLES (GEOSYNC) 27M SPACECRAFT (11) 12M VEHICLES (POLAR) 15M SPACECRAFT (11) 20M TRACKING 6M	LAUNCH PAD (GEOSYNC) 18M LAUNCH PAD (POLAR) 10M TRACKING 24M SYSTEM MANAGEMENT 4M		GEMINI, APOLLO PHOTOGRAPHY AIRBORNE IMAGERY (READY IN 1969/71 TIME FRAME)	COASTAL ENGINEERING HARBORING SHIPPING SEA FARMING/MINING RECREATION	URGENTLY NEEDED TO UPDATE RECORDS AND FACILITATE PLANNING, FREQUENCY, 1/YR
	<u>MARINE BIOLOGY</u> FISH SCHOOLS, MIGRATION PLANKTON, ALGAE (RED TIDE) BIOLUMINESCENCE <u>SEA FOOD PRODUCTION</u> UPWELLING CURRENTS BOTTOM TOPOGRAPHY OIL SLICKS SEA FARMING	20-200 m RESOLUTION SPECTRAL IMAGERY, SURFACE TEMPERATURE BY RADIOMETRY, SPECTROMETRY 100-300 m RESOLUTION IMAGERY (REAL TIME) 20-200 m RESOLUTION IMAGERY (REAL TIME), SPECTRA 100-300 m PHOTOGRAPHY	PROCESSING AND DISTRIBUTION SEGMENT SIGNATURE ANALYSIS AND R & D 2M	BUOYS 6M	BUOYS 4M DATA PROC. 8M SYSTEM MANGEMENT 8M	144M	NO PRECURSORS (READY 1973/75) IR NIMBUS, HRIR (LOW RES.) (READY 1973/75)	FOOD FROM THE SEA U.S. INSHORE MARKET FOR FISHING INDUSTRY IS $4 BILLION. ANY SMALL PERCENTAGE SAVINGS WILL QUICKLY GIVE BENEFITS MANY TIMES GREATER THAN SATELLITE PROGRAM	LARGE POTENTIAL PAYOFF, WEEKLY FREQUENCY LARGE POTENTIAL PAYOFF, FREQUENT COVERAGE NEEDED
	<u>SHIPPING</u> SEA STATE, STORM PATTERNS CURRENTS SEA ICE SHOALS AND WRECKS <u>SEA FLOOR MINING</u> BOTTOM TOPOGRAPHY <u>GROUND TRUTH</u>	300 m RESOLUTION IMAGERY/SCATTEROMETRY (REAL TIME AND AHEAD OF TIME COMPUTER MODELS) 100-300 m RESOLUTION IMAGERY 20 m RESOLUTION IMAGERY (REAL TIME), BUOYS 20 m RESOLUTION PHOTOGRAPHY/IMAGERY 20 m RESOLUTION PHOTOGRAPHY/IMAGERY BUOY PROGRAM, 10 BUOYS	TOTAL BOTH SEGMENTS			28M 172M	AIRBORNE SCATTEROMETRY HRIR IMAGERY AIRBORNE MICROWAVE IMAGERY GEMINI/APOLLO PHOTOGRAPHY } (READY 1971/73) GEMINI/APOLLO PHOTOGRAPHY (READY NOW) (READY 1969/71)	SEA TRANSPORT ECONOMY SAFETY AT SEA MINING THE SHALLOW SEAS (PLACER DEPOSITS, ETC.) CALIBRATION FOR SATELLITE DATA	LARGE POTENTIAL PAYOFF, FREQUENT COVERAGE NEEDED, AIRBORNE ICE SURVEY BY USCG OPERATIONAL SINCE WW2 PRESENTLY SPECULATIVE, FREQUENCY 1/YEAR
<u>HYDROLOGY</u> (HYDROLOGY PANEL) p. 11, 1967 30-33, 1967 3-1 TO 3-3, 1968	<u>WATER INVENTORY</u> LAKES AND RESERVOIRS [illegible] STREAM FLOW FORECAST SOIL MOISTURE, RAINFALL DISTRIBUTION SALT WATER INTRUSIONS *SNOW SURVEY SNOW WATER CONTENT* LIQUID-VAPOR TRANSFER AND CONSUMPTION HYDROLOGIC CYCLE; LARGE SCALE HYDROLOGIC SYSTEMS FORECAST OF PRECIPATION, TEMPERATURE AND STREAM FLOW	3 YEARS R & D, 4 YEARS OPERATION [illegible] IR AND RADAR IMAGERY SATELLITES SUPPORTED BY AIRCRAFT *RESOLUTION REQUIRED 20-100 m* GEOSYNCHRONOUS ORBITS, TOTAL OF 3 LAUNCHES POLAR SUN SYNCHRONOUS ORBIT, 2 LAUNCHES INCLUDING 2 SPARES	SPACE SEGMENT SPACECRAFT, SENSORS [illegible]	VEHICLES (GEOSYNC) [illegible] SPACECRAFT (11) 6M VEHICLES (POLAR) 15M SPACECRAFT (11) 5M TRACKING 5M	LAUNCH PAD (GEOSYNC) [illegible] LAUNCH PAD (POLAR) 10M TRACKING 16M SYSTEM MANAGEMENT 4M		[illegible] (ERTS-A)	NO $ BENEFITS BY 1968 PANEL BASIC UNDERSTANDING OF LARGE HYDROLOGIC SYSTEMS, IMPROVED MANAGEMENT OF WATER RESOURCES ESPECIALLY IN INACCESSABLE, UNDERDEVLOPED AND CONGESTED AREAS OF THE WORLD	SOME ASPECTS OF AREA CAN BE ATTACKED NOW, BASED ON LOW-RESOLUTION METEOROLOGICAL IMAGERY (WORLDWIDE) AND ON COLOR AND MULTISPECTRAL PHOTOGRAPHY
	<u>ENGINEERING WORKS</u> POLLUTION OF WATER FLOOD CONTROL TIDES AND EFFECTS IN HARBOR ESTUARIES DRAINAGE BASINS, RESERVOIRS TRANSPORTATION FRESH WATER SUPPLY RECLAMATION OF WATER	HCS-HYDROLOGIC COMMUNICATION SATELLITE HSS-1 HYDROLOGIC SENSING SATELLITE HSS-2 ADVANCED HYDROLOGIC SENSING SATELLITE 10,000 TO 40,000 GROUND SENSORS LINKED TO 10-40 REGIONAL HYDROLOGIC CENTERS.	PROCESSING AND DISTRIBUTION SEGMENT ANALYSIS, GROUND TRUTH 15M DATA PROC. 4M	UPDATE, EXPAND TRANSMITTERS 9M	TRANSMITTERS 4M DATA PROC (GEOSYNC) 20M DATA PROC (POLAR) 36M SYSTEMS MANAGEMENT 8M	105M	PRE 1975 POST 1975		CAPITAL INVESTMENT IN HYDROLOGIC ENGINEERING IS ENORMOUS. PER CAPITA USE OF WATER IN U.S. IS 70 GAL/MAN/DAY USGS PRESENTLY SPENDS $16M/YEAR TO OPERATE 6000 STREAM FLOW GAUGES
			TOTAL BOTH SEGMENTS			96M 201M			
<u>AGRICULTURE, FORESTRY, AND GEOGRAPHY</u> (PANEL ON A-F-G) p. 14-15, 1967 38-39, 1967 1-1 TO 1-5, 1968	<u>INVENTORY AND CLASSIFICATION</u> WORLD WIDE INVENTORY CROP SYSTEM PLANNING YIELD PREDICTION NATURAL VEGETATION SURVEY RANGE AND FOREST SURVEYS RECREATION SITE EVALUATION NON-CULTIVATED AREAS SOIL CLASSIFICATION LIVESTOCK CENSUS	EARTH RESOURCES TECHNOLOGY SATELLITES A-D (ERTS), 1975 FOLLOWED BY EARTH RESOURCES SATELLITES (ERS), POST 1975 EQUIPPED WITH MULTISPECTRAL IMAGERS (RBV), 100' RES-OLUTION, GROUND DATA COLLECTION CAPABIL-ITY, MICROWAVE AND RADAR SENSORS, SUP-PORTED BY SPACE PHOTOGRAPHY AND OTHER SENSORS AND AIRBORNE SENSING AND GROUND TRUTH	SPACE SEGMENT SPACECRAFT, SENSORS 14M GROUND NET 2M	VEHICLES 15M SPACECRAFT 5M GROUND STATION 4M	LAUNCH PAD 10M GROUND NET 8M		ERTS IS PRECURSOR OF ERS SERIES. OPERATIONAL PROGRAMS TO BE READY IN 1975, EVEN THOUGH RESULTS OF OPERATIONAL SIGNIFICANCE WILL BE OBTAINED IN 1971-1975 TIME FRAME.	WORLDWIDE AGRONOMY MANAGEMENT, INCREASED AND MORE EFFICIENT FOOD SUPPLY. BENEFITS OF MANY TENS OF MILLIONS OF DOLLARS PER YEAR INDICATED. URBAN, REGIONAL PLANNING BENEFITS EQUAL OR LARGER THAN IN AGRICULTURE/FORESTRY	MOST ADVANCE PROGRAM IN EARTH RESOURCES AREA, WITH EXPERIENCE IN NATIONWIDE DATA ACQUISITION AND HANDLING SIGNIFICANT PROGRESS BY AIRBORNE PROGRAMS IN RECENT YEARS. MANY COMPLEX ASPECTS (CROP VIGOR, ANIMAL LIFE, CROP STATUS AND SPECIES) WILL REMAIN AVAILABLE FOR STUDY IN MID 70's AND WILL BENEFIT FROM EXTENDED CAPABIL-ITY OF MANNED STATIONS.
	<u>PRODUCTION LOSS</u> INFESTATION OF DISEASE INFESTATION OF INSECTS FIRE DETECTION RECLAMATION <u>YIELD INCREASE</u> FARM PLANNING SOIL CLASSIFICATION, IRRIGATION AND OTHER REQUIREMENTS	NEAR-POLAR SUN SYNCHRONOUS ORBITS 3 YEARS R & D PLUS 4 YEARS OPERATION 5 POLAR ORB. LAUNCHES, 1 YEAR LIFE EA. 1 SPARE INCLUDED	PROCESSING AND DISTRIBUTION SEGMENT DATA ANALYSIS AND GROUND TRUTH 4M GROUND NET 2M CENTRAL PROC. 1M	GROUND NET 3M PROC. EQUIPMENT 3M	NETWORK 4M FILM PROC. PLUS SYSTEM MANAGEMENT 52M	58M			
	<u>INVENTORY OF MAN'S ACTIVITY</u> TOPOGRAPHIC MAPS LAND USE (WORKS OF MAN) HUMAN CENSUS <u>DYNAMIC PATTERNS OF ACTIVITY</u> RURAL AND URBAN DEVELOPMENT TRANSPORTATION FLOW <u>PHYSICAL GEOGRAPHY OF UNINHABITED AREAS</u> PHYSICAL AND BIOLOGICAL DESCRIPTION POTENTIAL FOR FUTURE USE		TOTAL BOTH SEGMENTS 23M	30M	74M	69M 127M			
<u>CARTOGRAPHY</u> (PANEL ON GEODESY - CARTOGRAPHY) p. 19-20, 44-45, 1967 NO 1968	<u>MAP MAKING</u>	METRIC CAMERAS, 12" FOCAL LENGTH, 9 x 9" FORMAT POLAR ORBIT AT LOW ALTITUDE	CARTOGRAPHY AND GEODESY WERE NOT SEPARATELY COSTED. CARTOGRAPHIC MISSION OBJECTIVES CAN BE ACHIEVED IN COMMONALITY WITH OTHER EARTH RESOURCES PROGRAMS IN GEOLOGY - GEOGRAPHY GEODETIC PROGRAM COSTS ARE ROUGHLY ESTIMATED AS $7M/YEAR OR, IN 7 YEARS			49M	AERIAL CAMERAS ARE AVAILABLE. SPACE SYSTEM CAN BE DEVELOPED ABOUT ONE YEAR AFTER GO AHEAD.	GOOD MAPS ARE A PREREQUISITE FOR ALL HIGH RESOLUTION EARTH RESOURCES PROGRAMS.	PACING ITEM IS DECISION TO GO AHEAD. METRIC CAMERAS OF LESS THAN 300 LBS WEIGHT ARE NOT DEVELOPED. THEREFORE LIGHTWEIGHT SYSTEMS FOR MANNED OR UNMANNED USE ARE IN NEED.
<u>GEODESY</u> (PANEL ON GEODESY - CARTOGRAPHY) p. 18, 42-43, 1967 NO 1968	<u>UNIFIED, MASS-CENTERED COORDINATE SYSTEM</u> GRAVITY FIELD (FIXED AND TIME VARIABLE)	LASER REFLECTORS, DOPPLER DEVICES, ALTIMETERS PASSIVE TRACKING BY GROUND CAMERAS (BAKER-NUNN STATIONS) GEDY 1-4 (1969-1972) 1 LOW INCLINATION, 3 POLAR ORBITS LOW INCLINATION (15° NOMINAL) AND POLAR ORBIT HIGH SENSITIVITY GRAVITY GRADIOMETER (ADAPTATION OF ICBM GUIDANCE SYSTEM)					GEOS A-B, ECHO I (PAGEOS B) GROUND NETWORK WITH STATIONS 2,00-4,500 KM APART, SECONDARY STATIONS 500-1000 KM APART. MILITARY SYSTEMS, SEVERAL YEARS DEVELOPMENT TIME POST-1975 TIME FRAME LIKELY	BENEFITS LARGELY INDIRECT (CARTOGRAPHY, OCEANOGRAPHY, ETC.) SPECIFICALLY, IMPROVED PREDICTION OF ORBITS, REDUCED TRACKING COSTS. (SAME AS ABOVE)	IDENTIFIED BENEFITS ROUGHLY EQUAL COSTS OF PROPOSED PROGRAM ($4-10 MILLION/YEAR) THE DECISION TO ACTIVATE THE PROGRAM IS CONSIDERED MAJOR PACING ITEM.
<u>GEOLOGY</u> GEOLOGY PANEL p. 16-17, 1967 40-41, 1967 2-1 TO 2-4, 1968	<u>MINERAL INVENTORY-PROSPECTING</u> FIELD MAPPING HIGH RESOLUTION MINERAL SENSING SPECTRAL SIGNATURE INTERPRETATION <u>SYNOPTIC PATTERN RECOGNITION</u> STRUCTURAL TRENDS HEAT BALANCE SPECTRAL PROPERTIES EROSIONS, DEPOSITIONS MAGNETISM AND GRAVITY ANOMALIES	COLOR PHOTOGRAPHY AND MULTISPECTRAL PHOTOGRAPHY WITH 100' RESOLUTION, 100 x 100 MILE FIELD OF VIEW PER EXPOSURE, SPECTRAL SENSORS IN NEAR AND THERMAL IR, AND IMAGERS IN ACTIVE AND PASSIVE MICROWAVE. LOW SUN ANGLE, SUN SYNCHRONOUS ORBITS 1 YEAR R & D, 3 YEARS OPERATIONAL 3 POLAR LAUNCHES REQUIRED ONE CLOUD-FREE COVERAGE PER YEAR SIMULTANEOUS AIRCRAFT COVERAGE OF NORTH AND SOUTH AMERICA HARD FILM RETURN OR VIDICON DATA TELEMETRY	SPACE SEGMENT SPACECRAFT, SENSORS 1M	VEHICLES 9M SPACECRAFT 3M RADAR SENSORS 2M	LAUNCH PAD 6M CAPSULE RECOVERY 1M RADAR FLIGHTS 11M		AIRBORNE RADAR AND OTHER SENSORS. SPACE PHOTOGRAPHY (APOLLO) GROUND TRUTH PROGRAM. POST-1975 IS PROJECTED READINESS FOR SPACE SYSTEMS.	REGIONAL GEOLOGIC PHOTO MAPS AS AIDS IN EXPLORATION. TOTAL ANNUAL EXPLORATION EXPENSE BY GEOLOGICAL/GEOPHYSICAL MEANS IN U.S. IS $500 MILL. ONLY 1% SAVINGS BY SPACE SENSING WILL WARRANT OPERATION. USGS ESTIMATES 7% EFFICIENCY INCREASE IN MAPPING PROGRAMS FROM SPACE	MANY RAW MATERIALS ARE GETTING IN SHORT SUPPLY, AND LOWER GRADE DEPOSITS ARE HARDER AND HARDER TO FIND. SYNOPTIC VIEW IS ONE OF THE ADVANTAGES OF SPACE OBSERVATIONS THAT LENDS ITSELF TO APPLICATION (SAME AS STUDYING GEOGRAPHY ON A GLOBE)
	<u>NATURAL DISTURBANCE MONITORING</u> EARTHQUAKE PREDICTION TSUNAMI WARNING VOLCANO WATCH FLOOD CONTROL RIVER DEPOSITION		PROCESSING AND DISTRIBUTION SEGMENT SIGNATURE ANALYSIS, GROUND TRUTH 2M		SYSTEM MANAGEMENT, PROCESSING 4M	33M	AIRBORNE FIRE WATCH IN WESTERN MOUNTAINS SINCE 1965	SAVINGS IN LIFE AND PROPERTY.	THE MILITARY HAS ALREADY EXPLOITED THE AREA OF DISTURBANCE MONITORING FOR THE PROTECTION OF THE FREE WORLD.
	<u>ENGINEERING GEOLOGY</u> GEOTHERMAL POWER LATENT LANDSLIDE MONITORING DAM, CANAL, AND TRAFFIC SURVEYS		TOTAL BOTH SEGMENTS 3M	14M	22M	6M 39M	IR AND MICROWAVE WORK FROM AIRCRAFT.	OPTIONAL DEVLOPMENT FOR TRAFFIC AND TRANSPORTATION. ENERGY (STEAM)	
<u>COMMUNICATIONS</u> PANELS ON a. POINT TO POINT, b. POINTS TO POINT, c. BROADCASTING p. 7-1 TO 7-3, 1967 9-1 TO 9-4, 1967 10-1 TO 10-4, 1967	<u>DATA PLATFORM COMMUNICATIONS</u> FIXED AND FLOATING BUOYS DATA COLLECTION RELAY SATELLITE FREQUENCY ALLOCATION DATA MANAGEMENT <u>POINT TO POINT COMMUNICATIONS</u> GEOSTATIONARY SYSTEMS (TELSTAR, RELAY, INTELSAT) ORBIT UTILIZATION PRINCIPLES MILLIMETER WAVE (BROADBAND) TECHNOLOGY MULTI-BEAM TECHNOLOGY SYSTEMOLOGY STUDIES <u>BROADCASTING</u> DISTRIBUTION TO GROUND FOR REBROADCAST COMMUNITY MANY-POINT BROADCAST DIRECT TV BROADCAST (EDUCATIONAL, UN, ETC.) VOICE BROADCAST (FM)	DCRS (DATA COLLECTION AND RELAY SATELLITE) TO READ OUT TENS AND HUNDREDS OF THOUSANDS OF STATIONS. 3 YEARS R & D, 4 YEARS OPERATION DOMESTIC SYSTEM AND INTERNATIONAL SYSTEM ARE OPERATIONAL. 5 GEOSYNCHRONOUS LAUNCHES REQUIRED 1 YEAR LIFETIME, 1 SPARE 15 POLAR LAUNCHES FOR DIRECT DELAYED READOUT SATELLITES, 3 SATELLITES SIMULT., 1 YEAR LIFETIME, 3 SPARES 20' ANTENNAS, 12 GHz 630 LB SATELLITE WITH 8 CHANNELS IN 3 TIME ZONES (TOTAL 24 CHANNELS) 25 GHz FM SYSTEM, 8' ANTENNAS, 975 LB SATELLITES THREE 5800 LB SATELLITES, 100 GHz, 2300 LB SATELLITE, 10 CHANNELS ON CONTINENTAL SCALE	GEOSYNCHRONOUS PORTION R & D 32M 4 SPACECRAFT 40M 4 LAUNCH VEHICLE 60M 3 GROUND STATIONS 23M 155M		POLAR ORBITER PORTION R & D 1M SPACECRAFT 32M 12 LAUNCH VEHICLES 60M 248M	403M	ERTS A (1971) WILL READOUT 6000 STATIONS/ORBIT READOUT CAPABILITY. BY 1975 SEVERAL PRECURSORS WILL HAVE PERFORMED. ATS, INTELSAT, TELSTAR, RELAY SYSTEMS ARE PRECURSORS. SYSTEMS ARE READY. POINT TO POINT COMMUNICATIONS IS PRECURSOR, MID-1975 LIKELY	LARGE-SCALE GROUND-TRUTH DATA COLLECTION FOR SPACE ACQUIRED SENSOR DATA REDUCTION IMPROVED COMMUNICATIONS AT LOWER COSTS. BENEFITS WILL EXCEED COSTS IMPROVED, MORE EFFICIENT COMMUNICATIONS. COST BENEFIT ADVANTAGE OF INCENTIVE INDUSTRY GREATLY EXCEEDS THAT TO AVIATION INDUSTRY	NEEDED FOR ALL DISCIPLINES PANEL REQUESTS ASSIGNMENT OF FREQUENCIES: 108 MHz FOR FM DIRECT BROADCAST, 470-840 MHz FOR DIRECT TO HOME BROADCAST, 2500 MHL FOR ETV, PUBLIC TV SERVICES, 12 GHz FOR DISTRIBUTION SERVICE, ALLOCATIONS IN 18 GHz, 35 GHz BANDS FOR FUTURE USE, ALLOCATIONS OF CLEAR CHANNELS IN UHF BAND FOR SPACE BROADCASTING
<u>NAVIGATION AND TRAFFIC CONTROL</u> PANEL ON NTC p. 25-26, 1967 55-57, 1967 11-1 TO 11-3, 1968	<u>AIR TRAFFIC CONTROL OVER NORTH ATLANTIC</u> SEA TRAFFIC CONTROL IN CONFLUENCE AREAS SEARCH AND RESCUE AT SEA	GEOSTATIONARY SATELLITE COVERING NORTH ATLANTIC	NAVIGATION AND TRAFFIC CONTROL INCLUDED IN COMMUNICATIONS				LIMITED PARTICIPATION EXPERIMENT (9 AIRLINES) HAS BEEN PERFORMED USING ATS SATELLITES.	SAFETY	
			GRAND TOTAL FOR SEVEN YEAR PERIOD			1,427M			

TABLE 2

DOLLAR BENEFITS FROM SPACE APPLICATIONS (WORLD WIDE)
($$10^6$ WHERE QUANTIFIED)

ACTIVITY	TRW (1) *	SUMMER STUDY 1967 *	SUMMER STUDY 1968 *	PRC (2) (FIVE CASE STUDIES) *●
AGRICULTURE/FORESTRY	40-60	10's	"MANY 10's"	1. RICE: INCREASED PRODUCTION ~ 20 2. WHEAT RUST CONTROL ~ 300
HYDROLOGY (WATER RESOURCES)	35-100	"SUBSTANTIAL"	"ENORMOUS"	3. POWER MANAGEMENT ~ 40 (HYDROELECTRIC)
GEOGRAPHY (LAND USE PLANNING)	10-50		"MANY 10's"	4. MALARIA CONTROL ~ 80
METEOROLOGY		~ 1000	(NOT QUANTIFIED)	
GEOLOGY (MINED RESOURCES)	100-600	~ 2000	(NOT QUANTIFIED)	
OCEANOGRAPHY (MARINE RESOURCES)	500-900	100's	"MANY TIMES GREATER THAN COST (NO DOLLAR ESTIMATE	5. FISH: ALBACORE TUNA ~ 150

1. WALTZ, DONALD; "TECHNOLOGICAL BASE FOR PLANNING OF SPACEFLIGHT MISSIONS TO OBTAIN DATA ON THE EARTH'S RESOURCES", TRW SYSTEMS, INCL. AIAA PAPER #68-1074.

2. MUIR, A.H.; SUMMERS, R.A., (NASA); "THE USE OF ECONOMIC BENEFIT ANALYSIS IN EARTH RESOURCES SATELLITE SYSTEM PLANNING", PLANNING RESEARCH CORPORATION, AIAA PAPER #68-1077

* ANNUAL

● COMPUTED OVER 20 YEAR PERIOD DISCOUNTED TO 1970. ANNUAL BENEFITS LESS EARLY IN PERIOD; GREATER LATE IN PERIOD.